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An Analysis of Preservice Elementary Teachers' Conceptual Difficulties in Learning Integrated Science Concepts

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Abstract: Learning science concepts presents significant challenges for students across all educational levels, especially in primary schools. However, little research has been carried out on preservice teachers' understanding of core science principles at Colleges of Education. This study examined the conceptual difficulties faced by preservice teachers when learning integrated science using a cross-sectional survey design. Data were collected through a two-tier diagnostic test administered to 255 preservice teachers, who were selected through simple random sampling. The average item difficulty index scores for basic electronics, balancing chemical equations, and infectious and non-infectious diseases were 0.35, 0.19, and 0.26, respectively. The study identified 75 alternative conceptions, including both factual and conceptual misunderstandings, with the greatest challenges found in balancing chemical equations and basic electronics. In basic electronics, preservice teachers exhibited 41 alternative conceptions, consisting of 23 (56.1%) factual and 18 (43.9%) conceptual misunderstandings. For balancing chemical equations, 26 were identified: 17 (65.4%) factual and 9 (34.6%) conceptual. In infectious and non-infectious diseases, eight were recorded, with 5 (62.5%) factual and 3 (37.5%) conceptual. Overall, balancing chemical equations posed the most difficulty, followed by infectious and non-infectious diseases and basic electronics. The study recommends implementing instructional strategies that promote conceptual change to improve preservice teachers' understanding and reduce misconceptions. The educational implications of these findings are discussed.

Keywords: alternative conceptions, conceptual difficulties, integrated science, preservice teachers.

Introduction

Science education in Ghana progresses from basic to higher levels, with foundational learning taking place during primary and secondary schooling. Scholars and policymakers recognise the crucial role of early science education in promoting future scientific inquiry and environmental responsibility (Adu-Gyamfi & Ampiah, 2016; Azure, 2015). A robust understanding of science fosters the development of ethical awareness and an appreciation for the interconnectedness of life, which are essential for sustainability in a modern world (Kooiker-den Boer et al., 2025; Pascual & Noble, 2025). Promoting science education at all pre-tertiary levels is therefore key to nurturing innovative, ethical, and scientifically literate individuals who can engage meaningfully with the natural world (Azure, 2015).

Integrated science, by design, combines concepts from multiple scientific disciplines to address real-world problems, encouraging holistic understanding and critical thinking (Winarno et al., 2020). As Ofori-Appiah et al. (2018) assert, effective teaching of integrated science is crucial not only for scientific literacy but also for economic and sustainable development. The interdisciplinary nature of integrated science reflects the evolving demands of contemporary education, where knowledge integration and dynamic instructional methods are emphasised (Arokoyu, 2012; Otarigho & Djagbo, 2013). However, these benefits are constrained when teachers lack sufficient content knowledge (Lee & Kriewaldt, 2025; Yadav et al., 2025), undermining the effectiveness of the dynamic process approach.

In Africa, integrated science has shown promise, particularly in countries like Ghana and Nigeria, where its implementation at the junior secondary level has yielded positive results (Sakpaku, 2016). As global development increasingly relies on science and technology, there is growing pressure to enhance scientific literacy across populations (Ansah et al., 2018). Ghana's commitment to this goal reflects the broader imperative to cultivate learners capable of developing, adapting, and applying scientific ideas through quality science education (MOE, 2010).

In Ghana, integrated science is a core subject taught across all pre-tertiary levels, primary, junior high, and senior high, as well as in tertiary institutions such as Colleges of Education and universities. The subject integrates four major disciplines: chemistry, biology, physics, and agricultural science (MOE, 2010). Its compulsory status at the pre-tertiary level and in teacher training colleges underscores its role in fostering scientific literacy and addressing real-world problems through interdisciplinary knowledge.

The primary objective of teaching integrated science is to support national development by equipping learners with scientific and technological competencies applicable to everyday life and environmental challenges (MOE, 2010). At the Colleges of Education, integrated science serves as a foundational course, preparing preservice teachers to teach science effectively at the basic school level. These teachers engage with key concepts across disciplines, including chemical equations, acids and bases, energy forms, electronics, photosynthesis, infectious diseases, and agricultural biotechnology.

Instruction at the primary level aims to nurture scientific thinking in both teachers and learners. As noted by Adu-Gyamfi and Ampiah (2016), the curriculum is designed to produce capable individuals who can advance scientific inquiry. To achieve this, teachers must foster both conceptual and procedural understanding, enabling students to investigate their environment and apply scientific principles meaningfully (MOE, 2010).

Developing students' scientific literacy and deep conceptual understanding is central to effective science education (Anim-Eduful & Adu-Gyamfi, 2022a). Conceptual knowledge enables learners to make sense of scientific phenomena through interpretation, application, and transfer of knowledge across contexts (Carrier et al., 2025). Learners with strong conceptual understanding are better equipped to solve problems, engage in abstract thinking, and connect disparate ideas (Anim-Eduful & Adu-Gyamfi, 2023). In contrast, procedural understanding focuses on the processes involved in scientific inquiry (Wang & Berlin, 2010).

Research has consistently identified integrated science concepts as challenging for learners (Mensah & Somuah, 2013; Somuah & Agyenim-Boateng, 2014; Twissel, 2018; Quansah et al., 2019). Specific concepts such as basic electronics, chemical equations, acids and bases, and infectious diseases are frequently cited as difficult for both teachers and students (Mensah & Somuah, 2013; Twissel, 2018). Adu-Gyamfi (2014) found that in-service teachers perceived electronics as particularly abstract and challenging to teach.

Numerous studies have reported that both students and teachers face conceptual difficulties in science, particularly in chemistry (Adu-Gyamfi et al., 2013, 2017; Anim-Eduful & Adu-Gyamfi, 2021, 2022b; Onder-Celikkanli & Tan, 2022), basic electricity and magnetism (Li & Singh, 2017; McColgan et al., 2017), and chemical equations (Baah & Ampiah, 2012; Dula, 2018). These difficulties are often rooted in misconceptions, ideas that deviate from accepted scientific explanations yet seem plausible to learners (Halim et al., 2014; Kuczmann & Budapest, 2017). Misconceptions can persist over time and hinder students' ability to construct accurate scientific understanding (Anim-Eduful & Adu-Gyamfi, 2021).

While numerous studies have explored students' conceptual difficulties in science—particularly in chemistry and physics most of these studies have focused on learners at the basic and senior high school levels (Baah & Ampiah, 2012; Kariper, 2011; Taber, 2011). These studies have highlighted persistent misconceptions in topics such as chemical equations, electricity, and acids and bases. However, there is a noticeable lack of empirical research investigating the conceptual understanding of preservice teachers, particularly those in Ghanaian Colleges of Education, who are being trained to teach integrated science at the basic school level.

Given that teachers' conceptual difficulties and weak content knowledge have been shown to impact student learning negatively (Anim-Eduful & Adu-Gyamfi, 2021, 2023), it is essential to examine the specific areas where preservice teachers struggle. Although WAEC chief examiners' reports continue to highlight poor student performance in areas like basic electronics and chemical equations, the literature has not adequately explored whether such challenges originate from the foundational training of these preservice teachers.

Moreover, evidence from the West African Examinations Council (WAEC) consistently highlights, in the chief examiners' reports, students' weak performance in basic electronics and chemical equations due to limited conceptual understanding (WAEC, 2013, 2015, 2016, 2018, 2021). For instance, the 2018 report noted students' inability to balance chemical equations involving the reaction of aluminium and hydrochloric acid (WAEC, 2018).

Furthermore, integrated science plays a central role in Ghana's pre-tertiary education, aiming to cultivate scientific literacy and problem-solving skills among learners. As preservice teachers in Colleges of Education are the future facilitators of science at the basic level, their conceptual understanding is crucial to effective science instruction. However, research has largely overlooked this group, focusing instead on learners at the basic and senior high school levels.

Existing literature and WAEC examiners' reports have persistently highlighted poor student performance in topics such as basic electronics and chemical equations, suggesting underlying instructional challenges. Studies have also shown that teachers' misconceptions and weak content knowledge can significantly affect learners' understanding (Anim-Eduful & Adu-Gyamfi, 2021, 2023). Investigating the conceptual difficulties of preservice teachers is therefore essential for identifying gaps in their training and informing targeted interventions in teacher education programs. This study is justified by the need to strengthen science teacher preparation in Ghana, ensuring that preservice teachers possess the depth of understanding required to teach integrated science effectively. By identifying specific areas of conceptual difficulty, this study provides empirical evidence to support curriculum review, pedagogical improvements, and policy decisions aimed at enhancing science education outcomes.

Beyond the Ghanaian context, a study conducted in Indonesia by Winarno et al. (2025) revealed that university pre-service teachers exhibited notable conceptual difficulties in the topic of vibration, a fundamental concept in physics. Similarly, research by Adlim et al. (2025), also in Indonesia, identified organic chemistry in the field of chemistry and Newman projection in physics as concepts that pre-service teachers found challenging to comprehend. These difficulties were attributed to the abstract nature of such concepts, which require advanced spatial reasoning and mental rotation skills to visualise and interpret molecular structures effectively.

In a related context, Kabapınar et al. (2025) reported that university pre-service teachers in Turkey demonstrated limited ability to construct evidence-based explanations and generate solutions to scientific problems during the process of scientific inquiry. This limitation may partly explain their tendency to merely define scientific concepts representing learning confined to the declarative learning domain—without providing deeper, conceptually grounded explanations for the occurrence of scientific phenomena, which would require engagement with the explicative learning domain.

Additionally, a study in Pakistan by Akram et al. (2022) examined conceptual difficulties faced by pre-service elementary teachers in general science. Their findings revealed that these teachers experienced challenges in understanding various chemistry-related concepts, such as chemical reactions and the properties of acids, as well as physics-related topics, including thermal contraction, expansion properties of liquids, radiation, ozone depletion, and air pollutants.

Furthermore, Ogundiji (2024) found that senior secondary school students in Nigeria demonstrated significant conceptual difficulties in balancing chemical equations, which were compounded by numerous factual inaccuracies. These challenges extended beyond procedural errors in applying balancing rules to deeper misunderstandings of atomicity, valency, and the mole concept, all of which are fundamental to chemical reasoning. Such findings point to a broader issue in science education where students lack both the factual accuracy and conceptual frameworks necessary for meaningful engagement with chemical problem-solving.

Importantly, these difficulties resonate with the challenges identified among pre-service teachers, who also display entrenched misconceptions in balancing chemical equations and other fundamental areas of chemistry. The persistence of such difficulties across educational levels suggests that misconceptions acquired during secondary schooling are not adequately addressed in teacher education programs and may, in fact, be perpetuated through ineffective instructional practices. This continuity highlights a systemic issue whereby algorithmic approaches are emphasised over conceptual understanding, reinforcing rote learning and obstructing the development of higher-order reasoning skills. Addressing this challenge requires a rethinking of both secondary science instruction and pre-service teacher preparation, ensuring that conceptual clarity and factual accuracy are prioritised as foundational components of science education.

In entirety, the findings of these studies suggest that the conceptual difficulties experienced by pre-service teachers contribute to the challenges elementary students face in grasping scientific concepts at both lower and higher educational levels. This connection can be explained by the well-established relationship between a teacher's mastery of subject matter and their instructional effectiveness; the depth of a teacher's conceptual understanding directly influences the quality of their explanations and pedagogical approaches, thereby affecting students' comprehension (Anim-Eduful & Adu-Gyamfi, 2021, 2022b).

Given this context, there is a clear and critical need to examine the conceptual difficulties experienced by preservice teachers in core integrated science topics, such as basic electronics, balancing chemical equations, and infectious and non-infectious diseases, to inform curriculum and instructional design at the college of education level. Such insights are essential for informing instructional strategies and improving teacher preparation.

Research Problem

Examining the conceptual difficulties faced by preservice teachers in the College of Education who are trained to teach integrated science is crucial to enhancing science education. Misconceptions in core areas risk perpetuating scientific misunderstandings and hindering the development of scientific literacy. Given the interdisciplinary demands of integrated science, such difficulties often reflect systemic shortcomings in teacher preparation. This study provides evidence to guide targeted remediation, particularly in the context of STEM-focused educational reforms. Addressing these gaps is essential for enhancing teacher quality, curriculum design, and student outcomes.

Consequently, this study on preservice teachers' conceptual difficulties in integrated science offers significant societal benefits by enhancing the quality of science education, promoting scientific literacy, and supporting STEM-focused educational reforms. Identifying and addressing misconceptions early in teacher preparation prevents the transmission of misinformation, informs curriculum design with targeted interventions, and empowers future teachers through reflective practice and professional growth. Strengthening teachers' content and conceptual understanding not only improves classroom instruction but ultimately contributes to national development goals by fostering a scientifically literate, innovative, and problem-solving citizenry.

The study's research problem was sufficiently developed, both conceptually and contextually. It is anchored in the global discourse on science education, particularly within the framework of teacher preparation and scientific literacy. The investigation into preservice teachers' conceptual difficulties in integrated science addresses a critical educational need: ensuring that future science educators possess a deep and accurate understanding of the concepts they are expected to teach.

The two-tiered diagnostic testing, particularly the reason-tier responses, will prove effective in revealing and documenting hidden and unique misconceptions, which will provide insights to offer empirical guidance for curriculum reform, targeted pedagogical interventions, and informed policy decisions aimed at enhancing science teacher education.

Research Focus

From a scientific standpoint, the main purpose of this study was **to** identify and examine the conceptual difficulties preservice teachers face in selected integrated science concepts—specifically, basic electronics, balancing chemical equations, and infectious and non-infectious diseases**.** By employing a diagnostic test framework, the study sought to reveal the types and prevalence of alternative conceptions held by preservice teachers, as classified by the National Research Council (1997). The findings offer empirical insights into areas of misconception and conceptual misunderstanding, thereby contributing to the broader discourse on science learning difficulties within preservice teacher education.

Research Aim and Research Questions

This study aimed to examine the conceptual difficulties of preservice teachers in Colleges of Education in selected integrated science topics: basic electronics, balancing chemical equations, and infectious and non-infectious diseases. The guiding research question is: *What conceptual difficulties do preservice teachers demonstrate in understanding basic electronics, balancing chemical equations, and infectious and non-infectious diseases in integrated science?*

Theoretical Framework

This study is underpinned by Conceptual Change Theory as proposed by Posner et al. (1982). Conceptual Change Theory provides a robust framework for understanding how learners revise or replace existing conceptions—often misconceptions—with scientifically accurate knowledge. It is particularly relevant in science education, where students and teachers alike may hold deeply rooted, intuitive understandings that conflict with accepted scientific explanations.

According to Posner et al. (1982), for conceptual change to take place, four key conditions must be satisfied: (1) dissatisfaction with existing conceptions—learners must recognize inconsistencies or inadequacies in their current understanding; (2) the new concept should be intelligible — clearly understandable within the learner's cognitive framework; (3) plausibility of concept — the learner must find it believable or applicable to real-world contexts; and (4) the concept should be fruitful — the new concept should offer greater explanatory power or problem-solving capability than the old one. Additionally, Posner et al. (1982) viewed meaningful learning to occur when students confront cognitive conflict between their prior conceptions and scientifically accurate explanations. In the context of integrated science, this model is essential because learners often hold entrenched misconceptions that hinder the development of scientifically accurate understanding across disciplines such as biology, chemistry, and physics.

In this study, pre-service teachers exhibited substantial conceptual difficulties and alternative conceptions in integrated science concepts, including basic electronics, balancing chemical equations, and infectious and non-infectious diseases. These misconceptions, categorised as conceptual misunderstandings and factual misunderstandings*,* align with the types of flawed cognitive structures the theory seeks to address. The theory thus supports the interpretation that many pre-service teachers have not yet experienced the cognitive conflict or dissatisfaction necessary to revise their misconceptions.

Moreover, the prevalence of these alternative conceptions suggests a lack of engagement with instructional strategies that promote conceptual change. Consequently, Conceptual Change Theory not only informs the analysis of the results but also justifies the need for instructional interventions that actively confront misconceptions, foster scientific reasoning, and guide learners through a process of cognitive restructuring.

By applying this framework, the study emphasises the importance of using pedagogical approaches that go beyond rote transmission of knowledge to those that challenge learners' prior conceptions and support meaningful learning. It also highlights the need for curriculum designers and teacher educators to integrate strategies that facilitate the rejection of erroneous beliefs and introduce intelligible, plausible, and fruitful scientific explanations.

Research in science education has consistently shown that learners, including pre-service teachers, enter formal instruction with pre-existing ideas that often diverge from scientifically accepted concepts. Specifically, studies have shown that misconceptions in areas such as basic electronics (Li & Singh, 2017; McColgan et al., 2017), chemical reactions (Adu-Gyamfi & Asaki, 2022, 2023; Anim-Eduful & Adu-Gyamfi, 2022b; Hanson, 2017), and biological processes are widespread among pre-service teachers and often mirror those found in the students they will eventually teach. These findings emphasise the cyclical nature of misconceptions, transmitted from teacher to learner, and highlight the importance of effective intervention at the teacher preparation stage. When unaddressed, they persist and obstruct the development of a coherent understanding of scientific phenomena.

In response to this challenge, Conceptual Change Theory (Posner et al., 1982) has become a foundational framework in understanding how learners restructure their prior knowledge. The theory posits that learners must first become dissatisfied with their current conceptions before adopting a new one, which must also be intelligible, plausible, and fruitful. This theoretical orientation underpins numerous empirical studies on science learning, which highlight the role of cognitive conflict and learner engagement in promoting conceptual learning.

The current study contributes to this body of work by identifying and classifying the alternative conceptions held by pre-service teachers in Colleges of Education in three domains of integrated science: basic electronics, balancing chemical equations, and infectious and non-infectious diseases. By adopting the lens of Conceptual Change Theory, this study interprets these alternative conceptions not simply as knowledge gaps, but as deeply entrenched cognitive structures that require explicit, targeted instructional strategies to shift. The findings reinforce the need for curriculum and pedagogical reforms that prioritise conceptual clarity and actively engage learners in resolving their misconceptions through evidence-based reasoning and scaffolded learning experiences.

Collectively, this theoretical framework emphasizes that integrated science education is not just about content delivery, but also about promoting cognitive restructuring, utilizing social and technological tools, and equipping teachers with the interdisciplinary skills needed to navigate complex classroom realities.

Methodology

Research Design

This study was grounded in the postpositivist research paradigm, which supports the empirical measurement and analysis of preservice teachers' conceptual difficulties in science. A quantitative research approach was adopted to obtain measurable data from a defined population. To enable data collection within a limited timeframe, a cross-sectional survey design was employed (Cohen et al., 2010; Creswell, 2014). This design facilitated the administration of a diagnostic test to assess preservice teachers' conceptual understanding of selected integrated science concepts.

Sample and Sampling Procedure

This study was conducted in the Eastern Region of Ghana, which had seven Colleges of Education during the 2022/2023 academic year. In Ghana, Colleges of Education are affiliated with traditional universities and follow a common curriculum based on their affiliating institution. Four of the seven colleges in the Eastern Region are affiliated with the University of Education, Winneba, and thus operate under a unified curriculum. Of these four, three colleges were selected through simple random sampling.

The population of pre-service teachers in the college averages 200 students at each level. This implies that there were 800 students in all four levels (Year 1, Year 2, Year 3, and Year 4) at each of the three colleges of education. The study population consisted of 2,400 pre-service teachers. The target population consisted of second-year pre-service teachers, 600 in total (200 from each of the three colleges). A total of 255 preservice teachers from the accessible population of 600 were randomly selected to participate in the study based on Krejcie and Morgan's (1970) sampling selection benchmark. According to Krejcie and Morgan (1970), a population of 600 requires a benchmark of 234 participants; thus, the selection of 255 preservice teachers involved in the study was appropriate.

The second-year pre-service teachers were selected to participate in this study because the concepts under investigation are taught in the second semester of the first year. At the time of data collection, year-one pre-service teachers had not yet learned these concepts; therefore, the second-year pre-service teachers were involved. This handed the second-years the opportunity to participate in this study, as they were in a better position to respond to diagnostic test items than the year-one, year-three, and year-four pre-service teachers. Given that students in Ghana can apply to any college regardless of their region of origin, the preservice teacher population across the 46 public Colleges of Education is relatively homogeneous.

Data Collection Instrument

The primary instrument for data collection was the self-developed Preservice Teachers' Diagnostic Test Instrument (PTDTI), designed to assess conceptual understanding and identify misconceptions in selected integrated science topics. The PTDTI was constructed concerning standard items from the literature and past West African Examinations Council (WAEC) assessments used in Ghana, The Gambia, and Nigeria, ensuring content validity.

The instrument comprised a two-tier diagnostic format. The first tier (Answer Tier, A-tier) consisted of multiple-choice items with four options, one correct and three distractors, used to assess preservice teachers' achievement in the targeted concepts. This tier generated the quantitative data. The second tier (Reason Tier, R-tier) required respondents to justify their selected answers by explaining the reasoning behind their choices. Responses in this tier were qualitatively analysed to identify conceptual difficulties and misconceptions. Together, the A-tier provided a measure of conceptual achievement. At the same time, the R-tier offered insight into preservice teachers' underlying reasoning, making it possible to evaluate both correct knowledge and alternative conceptions.

Validity and Reliability of Research Instrument

To ensure that the Preservice Teachers' Diagnostic Test Instrument (PTDTI) accurately measured preservice teachers' conceptual understanding, both content and face validity were established. The initial instrument was reviewed by two experts in science education and two experienced integrated science examiners. Their feedback was used to refine the content and structure of the test items. Additionally, English language experts reviewed the instrument to enhance clarity and eliminate ambiguity in wording.

Following these revisions, the instrument was pilot-tested with 25 preservice teachers from a College of Education in the Greater Accra Region. The pilot testing was conducted with a comparable group of preservice teachers to establish reliability and ensure clarity, with necessary modifications made based on item analysis and feedback. The diagnostic nature of the test enabled a detailed analysis of both factual and conceptual difficulties among respondents. Item difficulty indices were calculated, resulting in the removal of 11 items that were either redundant or fell outside acceptable difficulty ranges. These included four items from basic electronics, five from chemical equation balancing, and two from infectious and non-infectious diseases. The remaining items were reorganised and finalised for the main study.

The reliability of the instrument was determined using the Kuder-Richardson 21 (KR-21) formula, yielding a reliability coefficient of *.79*, indicating acceptable internal consistency. The final instrument consisted of 21 items: eight on basic electronics, seven on chemical equation balancing, and six on infectious and non-infectious diseases.

Ethical Procedures

This study adhered to established ethical standards for research involving human participants. Approval was obtained through an introductory letter from the Department of Science Education, granting access to the selected Colleges of Education. The purpose, procedures, and voluntary nature of participation were clearly explained, and informed consent was secured from all pre-service teachers. Confidentiality was strictly maintained, with no identifying information collected, and participants were assured that their responses would be used solely for academic purposes. They were also informed of their right to withdraw at any time without penalty. Data collection was conducted respectfully, non-coercively, and in full compliance with ethical research guidelines.

Data Collection Procedure

Data collection started after receiving official approval from the participating institutions, supported by an introductory letter from the Department of Science Education. Orientation sessions were conducted with pre-service teachers, where the study's purpose and procedures were explained, and voluntary informed consent was obtained. Eligibility was restricted to second-year pre-service teachers in three randomly selected Colleges of Education, as they had completed the relevant integrated science topics—basic electronics, balancing chemical equations, and infectious and non-infectious diseases—during their first year. First-year students were excluded due to lack of exposure, while third- and fourth-year students were excluded to prevent confounding effects of curriculum progression and specialisation. Data were collected over six working days, with two days allocated to each institution to allow sufficient time for test administration and participant clarification.

Data Processing and Analysis

The quantitative data obtained from the answer tier (A-tier) of the diagnostic test were analysed using descriptive statistics, including means, standard deviations, and percentages. These analyses provided an overview of preservice teachers' achievement in the selected integrated science concepts. The qualitative data, derived from the reason tier (R-tier), were analysed thematically to identify conceptual difficulties, following the classification framework proposed by the National Research Council (NRC, 1997).

According to the NRC (1997), science-related misconceptions can be grouped into five categories: i) Preconceived notions: these are popular beliefs formed due to incomplete observations or prior experiences of learners. It also views what is formed without proof or evidence, known as unconscious biases and prejudices.

ii) Nonscientific beliefs: students acquire beliefs from nonscientific sources, such as religious or mythical teachings.

iii) Conceptual misunderstandings occur when a general principle or example is misapplied, or concepts are misunderstood when learned.

iv) Vernacular misunderstandings: these are caused by a misunderstanding of the meaning of scientific words. For example, the scientific work could be misunderstood in its meaning by different people in their local dialect.

v) Factual misunderstandings: these are inaccurate or untrue science concepts that people frequently acquire early in life and continue to believe into adulthood. Such knowledge held by learners is contrary to what is accepted by the scientific community.

After analysing the A-tier responses, the R-tier justifications were examined to identify the nature and types of conceptual difficulties in basic electronics, balancing chemical equations, and infectious and non-infectious diseases. These justifications offered more profound insight into participants' reasoning and conceptual understanding. Responses were open-coded using the NRC's five-category framework, with frequency counts calculated and expressed as percentages to quantify the prevalence of each misconception. Non-justified responses (No Reason, NR) and blank entries were also recorded. Direct quotes from pre-service teachers were included to illustrate specific misconceptions and support the analysis.

Results

To address the research question, the conceptual difficulties of pre-service teachers in basic electronics, balancing chemical equations, and infectious and non-infectious diseases were analysed using their reasoning-tier (R-tier) justifications. The analysis focused on responses demonstrating partial scientific understanding (PSU) and no scientific understanding (NSU), as defined by Anim-Eduful and Adu-Gyamfi (2021), thereby excluding responses showing complete understanding across both tiers. Identified difficulties were categorised using the NRC's (1997) five classifications of alternative conceptions. However, the dominant misconceptions fell into two categories: conceptual misunderstandings, involving misapplications or misinterpretations of principles, and factual misunderstandings, reflecting inaccurate knowledge inconsistent with accepted explanations.

Furthermore, the difficulty level of each test item was evaluated using the Item Difficulty Index (IDI), calculated as the proportion of pre-service teachers who answered an item correctly relative to the total number of respondents, as presented in Table 1.

Table 1

Categorisation of Item Difficulty Indices

Proportions	Percentage (%) range	Description
0.0-0.40	0-40	Very difficult
0.50-0.60	50-60	Fairly difficult
0.70-0.80	70-80	Moderately difficult
0.90-1.00	90-100	Very easy

Generally, the diagnostic test items were found to be challenging for preservice teachers in Colleges of Education, with a mean Item Difficulty Index (IDI) of *.27*, indicating a generally low level of conceptual understanding across the tested concepts. The average IDI values for basic electronics, balancing chemical equations, and infectious and non-infectious diseases were *0.35, 0.19, and 0.26*, respectively. These results suggest that balancing chemical equations posed the most significant difficulty, followed by infectious and non-infectious diseases, and then basic electronics.

Analysis of the reason-tier responses revealed that the majority of preservice teachers exhibited conceptual difficulties in all three content areas. Among the five categories of alternative conceptions defined by the NRC (1997), only two conceptual misunderstandings and factual misunderstandings were identified in the data.

For example, Item 7 on basic electronics had an IDI of 0.40, indicating a high level of difficulty. Of the 208 preservice teachers (81.6%) who demonstrated conceptual difficulties on this item, only 9 (4.33%) provided explanations that could be classified as alternative conceptions: 4 (1.9%) exhibited conceptual misunderstandings, while 5 (2.4%) reflected factual misunderstandings. The remaining 199 (95.67%) failed to provide explanations that could be meaningfully categorised. One common factual misunderstanding observed was the incorrect belief that silicon in the compound SiO_2 is the primary component of sand. Excerpts illustrating these conceptual and factual misunderstandings in basic electronics are presented below.

Conceptual Misunderstandings**:** (i) *"Silicon is a non-metal; hence, it cannot be an ingredient of sand because it easily loses electrons and cannot be part of sand."* (Baaba)
(ii) *"Graphite is a metal obtained from the soil and often mixes with sand; therefore, it is the main ingredient of sand."* (Elorm)

Factual Misunderstanding: *"Glass is a component of sand because it is obtained from the ground and forms part of sand."* (Efua)

Item 8 also posed considerable difficulty, with an IDI of 0.43. Among the 170 preservice teachers (66.6%) who showed conceptual difficulties, only 4 (2.35%) provided alternative conceptions: 2 (1.2%) reflected conceptual misunderstandings and 2 (1.2%) factual misunderstandings, while 166 (97.65%) gave no valid explanation. The misconception identified was that the primary function of a resistor is to prevent excess current and conserve energy.

Excerpts illustrating conceptual and factual misunderstandings in Item 8 are presented below.

Conceptual Misunderstandings: (i) *"The presence of bulbs enables the LED to light up because bulbs prevent excess current from flowing through the conductor and store energy."*
(ii) *"The presence of a switch enables the LED to light up because it prevents excess current from flowing through the conductor and conserves energy."* (Kyeremeh)

Factual Misunderstanding: (i) *"The presence of wires in the LED helps it light up because wires contain and direct current through them."* (Gyasi)

These responses reflect fundamental misconceptions about the role of components in an electric circuit, particularly the function of resistors, switches, and conductors in enabling an LED to operate.

Item 9 was found to be highly difficult, with an Item Difficulty Index (IDI) of 0.40. Among the 157 preservice teachers (61.5%) who demonstrated conceptual difficulties, only 4 (2.54%) provided responses that could be classified as alternative conceptions—2 (1.27%) as conceptual misunderstandings and 2 (1.27%) as factual misunderstandings. The remaining 153 (97.45%) offered no valid explanations regarding the function of PNP and NPN transistors, particularly the direction of current flow from emitter to collector in NPN, and from collector to emitter in PNP transistors.

Conceptual Misunderstanding: (i) *"PNP transistors serve as emitter and collector because they prevent current from the emitter from being collected, as they are arranged in the opposite direction of current flow."* (Kofi)

Factual Misunderstandings: (i) *"NPN transistors serve as emitter and collector because they cut current flow during power outages as they are arranged to oppose current."* (Ama)
(ii) *"Only PNP transistors serve as emitter and collector because they can absorb and discharge current as emitters."* (Ben)

These misconceptions suggest a limited understanding of transistor functionality and the direction of current flow in circuit configurations.

Item 10 posed considerable difficulty for pre-service teachers, with a difficulty index of 0.38. Among the respondents, 210 (82.4%) demonstrated conceptual difficulties. Of these, only 6 (2.86%) provided explanations reflecting alternative conceptions. Additionally, 3 (1.42%) explanations were categorised as conceptual misunderstandings, and another 3 (1.42%) as factual misunderstandings. In comparison, the vast majority — 204 (97.14%) — failed to provide any explanation, indicating an understanding that Light Emitting Diodes (LEDs) are energy efficient due to their low current requirements in powering high loads. Excerpts highlighting these misconceptions include the following:

Conceptual misunderstanding: (i) *"LED consumes energy, hence preferred to other bulbs because LED bulbs have different colours, hence consume much energy"* (Kyeremeh).

Factual misunderstandings (i) *"Because all LED bulbs are rechargeable, they are preferred to other bulbs"* (Adwoa).

ii) *"Because all LED bulbs are energy inefficient due to their technology, they are preferred to other bulbs"* (Fiifi).

These excerpts highlight gaps in the fundamental understanding of LED functionality, particularly in terms of energy consumption and efficiency.

Item 11 was notably challenging for pre-service teachers, with a difficulty index of 0.35. A total of 238 (93.4%) pre-service teachers exhibited conceptual difficulties. Of these, 7 (2.94%) provided responses reflecting alternative conceptions, 5 (2.1%) demonstrated conceptual misunderstandings, and 2 (0.84%) were categorised as factual misunderstandings. The vast majority — 231 (97.14%) — failed to offer scientifically accurate explanations recognising that, upon the formation of a p-n junction, electrons from the n-type region diffuse into the p-type region, leaving behind positively charged donor ions. In contrast, holes from the p-type region similarly diffuse into the n-type region, resulting in negatively charged acceptor ions. This process leads to the formation of a depletion region and an internal electric field. Excerpts illustrating these misconceptions include:

Conceptual misunderstandings: (i) *"When the P-N junction diode is not connected to any current, the electric potential of the system is the same everywhere because the P-N junction diode does not have an effect whether connected to any current or not"* (JB).

(ii) *"The P-type has a higher potential than the N-type side flow when the P-N junction diode is not connected to any current"* (Gyasi).

Factual misunderstanding: (i) *"There is an electric field at the junction directed from the P-type side to the N-type side when the P-N junction diode is not connected to any current because the P-type side to the N-type side are connected in series and parallel at the same time"* (Okum).

These responses reveal a limited understanding of charge carrier dynamics, electric potential distribution, and field formation at equilibrium in semiconductor junctions.

Item 12 proved very difficult for pre-service teachers, with a difficulty index of 0.39. Out of 237 (93.0%) pre-service teachers who demonstrated conceptual difficulties, only 2 (0.84%) provided explanations reflecting alternative conceptions. Both of these explanations were classified as factual misunderstandings. The remaining 235 (99.2%) failed to articulate a scientifically accurate explanation, indicating that the p-type semiconductor contains a large number of holes, which serve as the majority charge carriers. These holes facilitate the flow of electric charge in the p-type material. Excerpts illustrating the factual misunderstandings include:

Conceptual misunderstandings: (i) *"Majority charge carriers in P-type semiconductor are electrons because electrons carry negative charges and there are numerous amounts of electrons in P-type semiconductor"* (Peace).
ii) *"Equal charge carriers in P-type semiconductor because of the volatility of P-type semiconductor"* (Ama).

These responses reflect fundamental misconceptions regarding carrier concentration and charge transport in doped semiconductors.

Item 13 was moderately challenging, with a difficulty index of 0.54. A total of 236 (92.5%) pre-service teachers exhibited conceptual difficulties. Among these, 2 (0.85%) provided explanations categorised as alternative conceptions, both of which were classified under factual misunderstandings. The remaining 234 (99.2%) could not provide an accurate explanation that, under reverse bias—when the P-end of the P–N junction is connected to the battery's negative terminal and the N-end to the positive terminal—the junction acts as an insulator, preventing current flow. Representative excerpts of the factual misunderstandings are:

Factual misunderstanding: (i) *"Because a conductor carries ions, when the P-end of the P-N junction is connected to the negative terminal of the battery and the N-end to the positive terminal, the P-N junction behaves like a conductor"* (Papa).
ii) *"Because a semiconductor lacks electrons, when the P-end of the P-N junction is connected to the negative terminal of the battery and the N-end to the positive terminal, the P-N junction behaves like a semiconductor"* (Amoasi).

These misconceptions underscore a limited understanding of semiconductor biasing and charge carrier behaviour under reverse voltage conditions.

Item 14 was highly difficult for pre-service teachers, with a difficulty index of 0.28. A total of 230 (90.2%) participants exhibited conceptual difficulties. Of these, 7 (3.04%) provided alternative conceptions, 5 (2.2%) were categorised as factual misunderstandings, and 2 (0.87%) as conceptual misunderstandings. The remaining 227 (98.7%) did not provide scientifically sound explanations for how capacitors function to store electric charge temporarily. The excerpts of conceptual misunderstandings presented on basic electronics and factual misunderstandings are:

Conceptual misunderstandings: (i) *"Light emitting diode charges and discharges current temporarily due to its emitting properties"* (Abbam).

(ii) *"Transistor charges and discharges current due to its ability to store and resist current flow"* (Efua).

Factual misunderstanding: (i) *"Inductor charges and discharges current due to its ability to stabilise current flow"* (BB).

These responses reflect a conflation of the functions of various electronic components, particularly a misattribution of charge storage properties.

Item 15 also presented significant difficulty, with an index of 0.08. Out of 242 (94.7%) pre-service teachers who demonstrated conceptual difficulties, 4 (1.7%) gave explanations reflecting alternative conceptions, while 2 (0.83%) were classified under both conceptual and factual misunderstandings. A majority — 238 (98.3%) — failed to correctly explain that iron metal reacts with oxygen gas to form iron(II) oxide (FeO). The excerpts of conceptual misunderstandings presented on balancing chemical equations and factual misunderstandings are:

Conceptual misunderstanding: (i) *"Because one mole of iron (II) ions (Fe^{2+}) has a charge of 2, it reacts to form iron (III) ions (Fe^{3+}) before reacting with one mole of an oxide ion (O^{2-}) to form Fe_3O_2"* (Baaba).

Factual misunderstandings: (i) *"Because the oxide ion (O^{2-}) gains one more electron from Fe to form O^{-}, hence the formation of FeO_2"* (Nimo).
ii) *"Because the oxide ion (O^{2-}) loses one electron and Fe gains one electron to form O^{-} and Fe^{3+}, hence the formation of Fe_3O"* (Essel).

These responses indicate persistent misconceptions concerning the assignment of oxidation states and the principles governing compound formation in basic chemical reactions.

Item 16 had a difficulty index of 0.18. Among 226 (88.6%) pre-service teachers who faced conceptual difficulties, 7 (3.1%) responses were alternative conceptions, 2 (0.89%) were conceptual misunderstandings, and 5 (2.21%) were factual misunderstandings. A significant portion — 219 (96.9%) — could not articulate that in a balanced chemical equation, the number of atoms of each element must be equal on both the reactant and product sides. The excerpts of conceptual misunderstandings, balancing of chemical equations, and factual misunderstandings are:

Conceptual misunderstandings: (i) *"$CH_4 + O_2 \rightarrow H_2O + CO_2$ is a balanced chemical reaction because carbon, hydrogen, and oxygen atoms are present on both sides"* (Adu).
ii) *"$HCl + Mg \rightarrow MgCl_2 + H_2$ is balanced because hydrogen, chlorine, and magnesium atoms appear on both sides of the equation"* (Ivy).

Factual misunderstanding: (i) *"$H_2 + N_2 \rightarrow NH_3$ is balanced because one mole of hydrogen reacts with one mole of nitrogen to produce ammonia"* (Regina).

These reflect a surface-level interpretation of balancing based on the presence of elements, rather than atom count or stoichiometry.

Item 17 had a difficulty index of 0.31. Of the 248 (97.3%) pre-service teachers with conceptual difficulties, 5 (2.0%) responses were alternative conceptions, 2 (0.81%) were conceptual misunderstandings, and 3 (1.21%) were factual misunderstandings. The majority—243 (98.0%)—did not recognise that the reaction between sodium sulphate and barium chloride forms a white precipitate of barium sulphate and soluble sodium chloride. Selected misconceptions include:

Conceptual misunderstandings: (i) *"$C_8H_{18}(g) + 25/2\ O_2(g) \rightarrow 8\ CO_2(g) + 9\ H_2O(g)$ is a double displacement reaction because there is formation of carbon dioxide and water"* (Fiifi).
ii) *"$2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$ is a double displacement reaction because magnesium displaces hydrogen"* (Efua).

Factual misunderstanding: (i) *"$2N_2O_5(g) \rightarrow 2N_2(g) + 5O_2(g)$ is a double displacement reaction because one molecule decomposes into nitrogen and oxygen gases"* (Amoani).

These explanations reveal a poor understanding of reaction types, particularly the distinctions between displacement, decomposition, and combustion reactions.

Item 18 was complicated for pre-service teachers, with a difficulty index of 0.25. Of the 237 (93.0%) participants who exhibited conceptual difficulties, 4 (1.7%) provided responses reflecting alternative conceptions. The remaining 233 (98.3%) were unable to explain that calcium hydroxide reacts with ammonium chloride to produce ammonia gas, calcium chloride, and water. The excerpts of conceptual misunderstandings presented on balancing chemical equations and factual misunderstandings are:

Conceptual misunderstanding: *"The products formed when one mole of calcium hydroxide reacts with ammonium chloride are calcium chloride and water because there is oxygen in calcium hydroxide that produces the water"* (Ama).

Factual misunderstanding: *"The products formed when one mole of calcium hydroxide reacts with ammonium chloride are calcium chloride and ammonia"* (Ben).

These responses show confusion in identifying all products of the reaction, particularly the formation of ammonia gas.

Item 19 had a difficulty index of 0.24. Of the 233 (91.4%) pre-service teachers with conceptual difficulties, 2 (0.86%) provided alternative conceptions, while one (0.84%) response each was classified under conceptual and factual misunderstandings. A majority of 231 (99.1%) could not explain that hydrogen gas is released when hydrochloric acid reacts with an active metal such as zinc, due to its electropositive nature. The excerpts of conceptual misunderstandings presented on balancing chemical equations and factual misunderstandings are:

Conceptual misunderstanding: *"Zinc is a very unreactive metal; hence, it reacts with acids to liberate carbon dioxide gas"* (Papa).

Factual misunderstanding: *"Hydrochloric acid reacts with zinc metal to liberate ammonia gas because zinc reacts with concentrated hydrochloric acid"* (Ebenezer).

These reflect a lack of understanding regarding typical acid-metal reactions and the gaseous products formed.

Item 20 proved to be very difficult (index = 0.25). Among the 238 (93.4%) pre-service teachers with conceptual difficulties, 2 (0.84%) gave responses reflecting alternative conceptions. One explanation (0.42%) each was identified as a conceptual and a factual misunderstanding. The majority (99.6%) were unable to correctly explain that reactants are the starting substances in a chemical equation and are written on the left side of the equation. The excerpts of conceptual misunderstandings presented on balancing chemical equations and factual misunderstandings are:

Conceptual misunderstanding: *"Aluminium trioxonitrate (V) and sodium hydroxide are formed when aluminium trioxonitrate (V) reacts with sodium hydroxide"* (Erica).

Factual misunderstanding: *"Sodium hydroxide is formed when aluminium trioxonitrate (V) reacts with sodium hydroxide"* (Prempeh).

These suggest that students are confused between reactants and products in chemical reactions.

Item 21 recorded a very low index of 0.11. Out of 248 (97.3%) pre-service teachers with conceptual difficulties, 2 (0.81%) presented alternative conceptions, and 2 (0.81%) had factual misunderstandings. A vast majority (99.2%) could not provide an accurate description of product formation. The excerpts of factual misunderstandings presented on balancing chemical equations are:

Factual misunderstandings: **(**i) *"Aluminium metal reacts with copper (II) chloride to yield aluminium chloride and copper metal"* (Bernice).

(ii) *"Aluminium hydroxide and sodium trioxonitrate (V) are formed when aluminium reacts with copper (II) chloride"* (Mathias).

These reflect confusion about the substances involved in single-displacement and double-displacement reactions.

Item 22 was complicated (index = 0.03). Of the 160 (94.7%) pre-service teachers with conceptual difficulties, none provided responses that could be categorised as alternative conceptions. Most were unable to explain that aluminium metal reacts with copper chloride ions, resulting in aluminium dissolving and copper precipitating.

Item 23 also showed high difficulty, with an index of 0.22. Of the 196 (76.9%) pre-service teachers with conceptual difficulties, none provided alternative conceptions. Few were able to explain the thermal decomposition of sodium bicarbonate into sodium carbonate, carbon dioxide, and water, represented by the balanced equation:

$$2NaHCO_3\,(s) \rightarrow Na_2CO_3\,(s) + CO_2\,(g) + H_2O\,(g). \qquad (1)$$

Item 24 was moderately strenuous for pre-service teachers with an index of .72. Of the 195 (77.3%) pre-service teachers with conceptual difficulties, none provided explanations and were categorised as alternative conceptions.

Item 25 was complicated for pre-service teachers, with an index of .24. Of the 209 (82.0%) pre-service teachers with conceptual difficulties, none provided explanations and were categorised as alternative conceptions.

Item 26 had a difficulty index of 0.36. Of the 196 (76.9%) pre-service teachers with conceptual difficulties, 5 (2.55%) demonstrated alternative conceptions. Two (1.0%) explanations were conceptual misunderstandings, and three (1.53%) were factual misunderstandings. In comparison, 191 (97.45%) failed to recognise that lifestyle factors do not transmit infectious diseases, as pathogens do not cause non-infectious diseases and cannot be transmitted between individuals.

Conceptual misunderstanding: *"It is not only protein that leads to kwashiorkor, but rather some of the nutrients that contain fats and oils may be added"* (Kojo).

Factual misunderstandings: (i) *"Beriberi is a lack of vitamin B2"* (Sala).
(ii) *"Because Beriberi is caused by a lack of nutrients such as folic acid"* (Kofi).

These responses demonstrate a poor differentiation between infectious and non-infectious diseases, as well as limited nutritional knowledge.

Item 27**,** with an index of 0.01, was among the most difficult. Of the 157 (61.6%) pre-service teachers with conceptual difficulties, 3 (1.9%) presented alternative conceptions, 2 (1.27%) factual misunderstandings, and 1 (0.64%) a conceptual misunderstanding. Most (98.1%) could not explain that diseases are classified as pathogenic and non-pathogenic depending on whether microorganisms cause them.

Conceptual misunderstanding: *"Treated nets are meant for mosquitoes and not bacteria that cause typhoid"* (Abeiku).

Factual misunderstanding: (i) *"Safe disposal of sewage such that waste is not dumped into water bodies or around the environment"* (Charity).

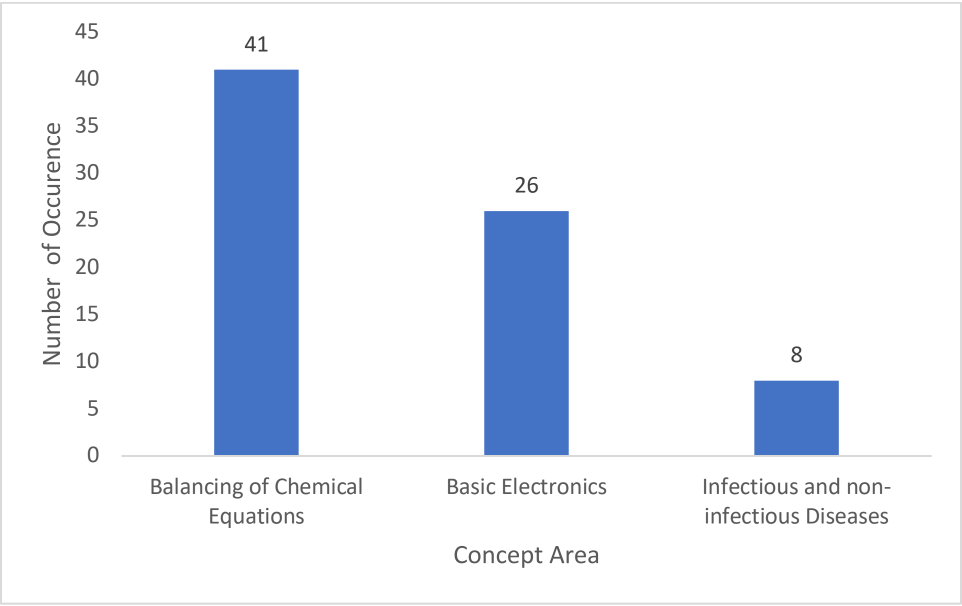
These misconceptions highlight confusion between disease transmission routes and disease classification.

To maintain confidentiality, pseudonyms are used; they do not represent actual participant names

Pre-service teachers in Colleges of Education displayed a total of 75 alternative conceptions across key areas of integrated science. These included basic electronics, balancing chemical equations, and infectious and non-infectious diseases. The most common, with 41 conceptions, were related to basic electronics. Next, 26 conceptions were in the domain of balancing chemical equations, and eight were noted in infectious and non-infectious diseases. The distribution of these conceptions is illustrated in Figure 1.

Figure 1

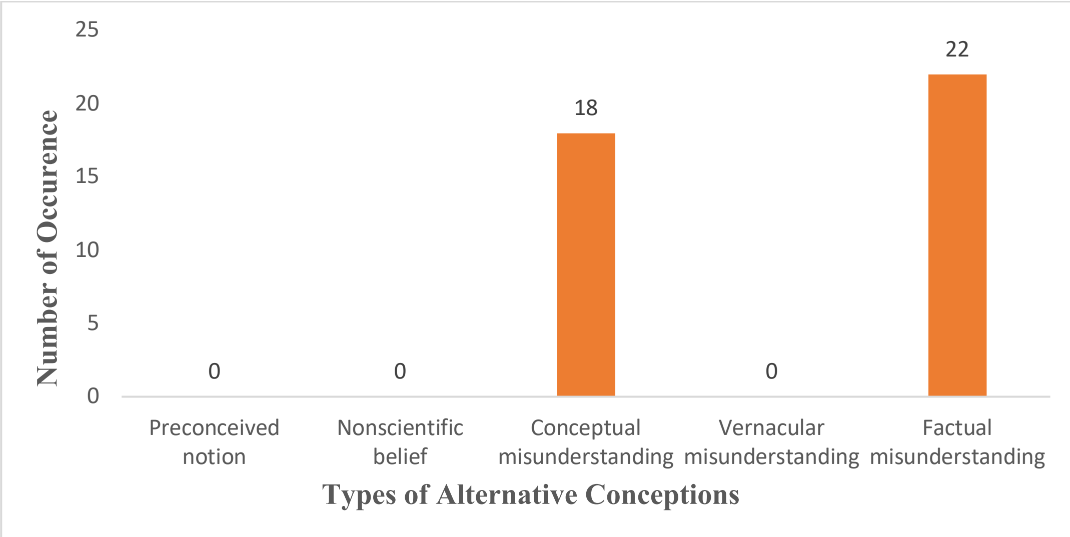
Proportion of Preservice Teachers' Alternative Conceptions in Integrated Science



In the domain of basic electronics, pre-service teachers exhibited a total of 41 alternative conceptions, of which 23 (56.1%) were categorised as factual misconceptions and 18 (43.9%) as conceptual misconceptions. Similarly, 26 alternative conceptions were identified in balancing chemical equations, comprising 17 (65.4%) factual and 9 (34.6%) conceptual misconceptions. For infectious and non-infectious diseases, eight alternative conceptions were recorded, with 5 (62.5%) being factual and 3 (37.5%) conceptual in nature. These findings indicate a predominance of factual misconceptions in basic electronics and chemical equation balancing, suggesting that pre-service teachers face greater challenges in comprehending concepts rooted in physics and chemistry than those in biology.

Figure 2

Proportion of Alternative Conceptions Demonstrated by Preservice Teachers



In this study, pre-service teachers demonstrated two out of the five categories of alternative conceptions classified by the National Research Council (NRC, 1997)—namely, conceptual misunderstandings *and* factual misunderstandings*.* This indicates that categories such as preconceived notions*,* nonscientific beliefs, and vernacular misunderstandings were not exhibited by the participants, as illustrated in Figure 2.

Discussion

The conceptual difficulties observed among pre-service teachers' likely stem from their limited scientific understanding of key topics in integrated science, basic electronics, balancing chemical equations, and infectious and non-infectious diseases. Consistent with Hanson (2017), who reported challenges among university-level pre-service teachers in associating symbols and formulas with chemical names, this study found that pre-service teachers in Colleges of Education also struggle with fundamental aspects of chemical reactions, including identifying products and applying correct stoichiometric coefficients in balanced equations.

Furthermore, building on earlier work, the findings of Adu-Gyamfi and Asaki (2022, 2023) and Anim-Eduful and Adu-Gyamfi (2022b) demonstrated that students encounter persistent challenges in organic chemistry, particularly in identifying functional groups and interpreting reaction processes. These struggles reflect the abstract nature of organic chemistry and are often compounded when teachers themselves hold similar misconceptions, leading to a reinforcement of errors across educational levels (Anim-Eduful & Adu-Gyamfi, 2021). Complementary studies reveal that difficulties extend beyond organic contexts into inorganic chemistry, where students and pre-service teachers struggle with balancing equations, applying mole concepts, and identifying limiting reagents issues that are largely procedural and quantitative in nature (Khmel & Shpyrka, 2025; Ogundiji, 2024). Similarly, in this study, conceptual barriers are also evident in biology, where pre-service teachers demonstrate difficulty distinguishing between infectious and non-infectious diseases, suggesting that the core challenge lies not only in disciplinary content but in the broader struggle to link surface knowledge with underlying mechanisms. Collectively, these findings emphasize that, across domains, over-reliance on rote memorization over conceptual understanding remains a systemic issue in science education.

A notable trend across the three conceptual areas — organic reactions, inorganic chemical equations, and disease concepts was that pre-service teachers who exhibited difficulties were often unable to justify their selected responses. This inability to provide reasoning highlights a surface-level engagement with scientific concepts, echoing earlier findings that students tend to rely on rote memorisation rather than meaningful understanding observed in organic chemistry, where learners struggle with the abstract nature of functional groups and reaction mechanisms without true comprehension (Adu-Gyamfi & Asaki, 2022, 2023; Anim-Eduful & Adu-Gyamfi, 2022b). The present data reinforce this view by revealing that of the 75 alternative conceptions identified, 45 (60.0%) were factual misconceptions, instances where pre-service teachers recalled incorrect information or misapplied definitions, while 30 (40.0%) were deeper conceptual misunderstandings, reflecting a lack of grasp of fundamental principles.

In inorganic contexts, difficulties with balancing equations, mole concepts, and limiting reagents reflect the same shallow engagement, as learners tend to memorise algorithms without understanding their logical basis (Ogundiji, 2024). Likewise, in biology, confusion between infectious and non-infectious diseases demonstrates a failure to connect terminological knowledge with mechanisms of transmission, underscoring the broader problem of disjointed reasoning across disciplines.

Taken together, these findings suggest that the learning difficulties of pre-service teachers are not simply random errors but follow a systematic pattern of surface-level engagement. By showing that factual misconceptions outweigh conceptual misunderstandings, this study underscores the urgent need for instructional approaches that emphasise reasoning, justification, and conceptual connections, rather than recall of fragmented information. Without addressing these gaps, there is a strong risk that future generations of students will inherit the same misconceptions, consequently perpetuating cycles of shallow learning in science education

It is worth noting that conceptual difficulties encountered by pre-service teachers in integrated science exert a significant influence on their scientific literacy and their capacity to contribute to economic and sustainable development through education. These difficulties may constrain their effectiveness in teaching such concepts at the basic and secondary school levels (Lee & Kriewaldt, 2025; Ofori-Appiah et al., 2018). Consequently, they impair pre-service teachers' ability to interpret, apply, and transfer scientific knowledge across contexts, competencies that are essential for fostering problem-solving skills, abstract reasoning, and integrative thinking (Adu-Gyamfi & Anim-Eduful, 2022; Anim-Eduful & Adu-Gyamfi, 2023; Carrier et al., 2025).

Furthermore, the findings show that pre-service teachers possess not only conceptual misunderstandings but also factual inaccuracies in essential areas such as basic electronics, chemical equations, acids and bases, and infectious diseases (Mensah & Somuah, 2013; Twissel, 2018). This double challenge highlights a broader weakness in both knowledge and conceptual reasoning, which hampers their ability to effectively support students' learning. Such evidence supports earlier research that repeatedly emphasises the difficulties linked to teaching and learning fundamental science concepts, including electricity, magnetism, and chemical reactions (Baah & Ampiah, 2012; Dula, 2018; Li & Singh, 2017; McColgan et al., 2017). At the same time, it extends this body of work by highlighting the continued presence of entrenched misconceptions among pre-service teachers in colleges of education, indicating that these problems are systemic and may be passed down through generations of learners if not addressed.

The finding that basic electronics was the most challenging concept for preservice teachers can be attributed to several interconnected factors. Firstly, the abstract nature of electronics makes it inherently challenging. Concepts such as electric current, voltage, resistance, and the behaviour of semiconductors are not directly observable, which forces learners to rely heavily on mental models and symbolic representations. These models can be difficult to grasp without prior exposure or adequate instructional support.

Additionally, many preservice teachers enter teacher education programs with limited or no background in electronics, particularly those who specialised in biology or general science during their secondary education. This lack of foundational knowledge creates a significant learning gap when they are introduced to electronics at the college level.

Another critical factor is the limited access to practical, hands-on experiences in many colleges of education. Practical activities such as constructing circuits or experimenting with resistors and transistors are essential for reinforcing theoretical concepts. In many colleges of education, however, access to well-equipped science laboratories is limited, and students may not have the opportunity to engage in meaningful practical activities that reinforce their theoretical learning. Without these opportunities, students struggle to connect abstract ideas with real-world applications, which hampers conceptual understanding.

Moreover, electronics requires some degree of mathematical competence, as it involves calculations based on principles like Ohm's Law. For students who lack confidence in mathematics, this adds a layer of difficulty. Compounding this issue is the reliance on traditional lecture-based teaching methods, which often fail to incorporate interactive tools such as simulations, visual aids, or inquiry-based learning strategies that could facilitate more profound understanding. Students' confusion surrounding technical terminology also plays a role. Terms like "current" and "resistance" may be misunderstood if not clearly explained or contextualised, leading to misconceptions. Additionally, the fragmented nature of the integrated science curriculum may isolate electronics from related concepts, preventing students from seeing how it connects to broader scientific principles.

In summary, the complexity of electronics, lack of exposure, insufficient practical experience, mathematical challenges, and inadequate pedagogical approaches collectively contribute to why preservice teachers find basic electronics complicated to understand. Addressing these issues requires targeted interventions in both curriculum design and instructional practice.

Despite the high level of difficulty across all three content areas, basic electronics (a physics-based concept) posed the greatest conceptual challenge, followed by balancing chemical equations (chemistry) and infectious and non-infectious diseases (biology). These findings highlight the persistent and widespread conceptual challenges that pre-service teachers encounter in learning integrated science, with implications for curriculum design and instructional strategies in teacher education programs.

Theoretical Implications

Theoretical Framework: Embodied Adaptive Apprenticeship (EAA)

The teaching and learning of integrated science often present persistent challenges, particularly in bridging abstract conceptual knowledge with practical application and reflective practice. While Posner's model of conceptual change has long been influential in explaining how learners restructure scientific misconceptions, it has been critiqued for its limitations in addressing the embodied, contextual, and adaptive dimensions of learning. Consequently, the limitations inherent in Posner's model highlight the need for a more robust theoretical framework, capable of addressing its shortcomings while advancing both teacher preparation and the adequate conceptualisation of abstract scientific concepts.

To address this gap, we propose a cohesive theoretical framework—Embodied Adaptive Apprenticeship (EAA**)** —that synthesizes insights from contemporary educational theories to guide both research and professional training in science education. EAA is substantiated by scholarship that foregrounds the interdependence of embodied cognition, cognitive apprenticeship, and adaptive learning, offering a holistic perspective on how learners construct knowledge, engage with authentic practice, and cultivate reflective dispositions for lifelong professional growth.

Embodied Cognition

Drawing from Embodied Cognitive Theory (ECT) (Yin & Goller, 2024), this component emphasises that cognition is not purely mental but fundamentally shaped by bodily action and sensorimotor experience. In the context of science education, embodied learning strategies—such as simulations, visualisations, and hands-on experimentation—transform abstract scientific principles into tangible, lived experiences. This embodiment enables learners to anchor their conceptual understanding in action, thereby deepening comprehension and facilitating knowledge transfer.

Cognitive Apprenticeship

The Cognitive Apprenticeship Model (CAM) (Dewhirst, 2023) extends traditional apprenticeship into modern educational contexts by situating learning within authentic practice. Through guided participation, modelling, coaching, and scaffolding, learners gradually acquire disciplinary ways of thinking and problem-solving. Within EAA, this component underscores the importance of structured opportunities for teacher candidates to apply theoretical insights in real classroom settings, thereby enhancing pedagogical readiness and confidence.

Adaptive Learning

The Master Adaptive Learner (MAL) framework (Wolff et al., 2023) highlights the necessity of metacognition, self-reflection, and adaptability in contemporary professional education. Adaptive learning involves not only acquiring knowledge but also developing the capacity to adjust strategies in response to new challenges. Within EAA, this adaptive dimension highlights the importance of reflective practice in developing resilient and flexible educators who embrace lifelong learning and ongoing professional development.

Synthesis and Implications of Embodied Adaptive Apprenticeship

By integrating these three perspectives, the Embodied Adaptive Apprenticeship (EAA) framework offers a theoretically rigorous and practically relevant approach to integrated science education. Embodied cognition provides the experiential grounding of knowledge, cognitive apprenticeship situates learning in authentic social contexts, and adaptive learning ensures that reflective practice and flexibility are embedded in the process. Collectively, these dimensions position EAA as a powerful model for:

1. Enhancing understanding through embodied simulations and visualisations: By situating abstract concepts in interactive, embodied, and visual contexts, learners can anchor their comprehension in concrete experiences. This not only fosters more profound conceptual clarity but also strengthens retention and transfer of knowledge to diverse real-world scenarios.

2. Enhancing pedagogical readiness through practical teaching experience: Opportunities for applied teaching practice serve as a bridge between theoretical knowledge and professional enactment. Through authentic classroom interactions, learners develop the confidence, adaptability, and pedagogical skills essential for effective instruction.

3. Enhancing reflective practice and promoting lifelong learning: Encouraging sustained self-reflection cultivates critical awareness of one's professional growth, challenges, and evolving needs. This reflective disposition nurtures adaptability and resilience, positioning lifelong learning as a cornerstone of continuous professional development.

To this end, these dimensions of EAA highlight how integrating experiential, reflective, and applied elements within professional training equips learners with not only the technical competence but also the adaptive mindset required for ongoing effectiveness and growth. In this sense, EAA provides both a conceptual lens for future research and a practical guide for teacher training, addressing long-standing challenges in integrated science while equipping educators and learners with the tools for enduring success.

Practical Implications

The findings of this study highlight the urgent need to implement more effective, research-based instructional strategies for teaching integrated science in Colleges of Education. Improving pre-service teachers' conceptual understanding requires deliberate efforts by science tutors to use pedagogical approaches that encourage conceptual change and explicitly challenge alternative conceptions.

Additionally, the science curriculum in Colleges of Education requires careful review. It is essential to determine whether tutors are effectively implementing the instructional strategies outlined in the curriculum or if the curriculum itself lacks sufficient provisions for participatory, inquiry-based learning that genuinely engages pre-service teachers. A systematic review of the curriculum by affiliated universities is therefore crucial for identifying the root causes of ongoing conceptual challenges and determining whether these issues primarily originate from curricular design, pedagogical practices, or a combination of both.

Consequently, curriculum restructuring is essential to address conceptual difficulties that preservice teachers may encounter before entering the classroom. Teacher training institutions should introduce diagnostic science modules early in science education programmes, incorporating pre-assessments of common misconceptions in physics, chemistry, and biology, followed by targeted remediation. Curricula should further emphasise integrated conceptual pedagogy that combines content mastery with strategies for fostering conceptual change. Courses should explicitly train preservice teachers to identify, interpret, and address misconceptions effectively. In addition, the integration of digital simulations and modeling tools, such as PhET and Tinkercad, is recommended to enhance understanding of abstract concepts and their practical applications. Embedding these tools within instructional activities will strengthen preservice teachers' conceptual grasp and prepare them to integrate technology meaningfully in their future classrooms.

Implementing these recommendations would ensure pre-service teachers develop scientifically accurate conceptions, enabling them to teach foundational science content more effectively. Conversely, neglecting these issues risks perpetuating a cycle in which misconceptions are passed from teachers to students, ultimately limiting science learning outcomes at both the elementary and senior high school levels.

Research Limitations

A significant limitation of this study concerns the diagnostic instrument used. While the two-tier diagnostic test offered valuable insights into pre-service teachers' misconceptions about concepts and facts, its dependence on multiple-choice formats with written justifications might not have fully captured the depth of participants' reasoning. Some responses could have reflected test-taking strategies rather than an accurate understanding. Furthermore, the lack of triangulation with other data sources, such as interviews, classroom observations, or practical tasks, may have restricted the comprehensiveness of the findings. As a result, the results should be viewed with caution, recognising that the instrument mainly uncovered surface-level conceptions rather than the full complexity of participants' cognitive processes.

Another limitation pertains to potential biases. Voluntary participation may have introduced self-selection bias, while response bias could have caused participants to offer expected rather than genuine justifications. Researcher bias in coding and interpretation also cannot be entirely ruled out. These factors may have influenced the nature and extent of the identified misconceptions, necessitating a cautious interpretation of the findings.

Another limitation of this study pertains to potential biases that may have affected the findings. As participation was voluntary, self-selection bias may have occurred, with more motivated or confident pre-service teachers opting to participate. Response bias is also possible, as participants could have provided justifications they believed were expected rather than truly reflecting their understanding. Moreover, researcher bias in coding and interpreting the open-ended responses cannot be entirely dismissed, despite efforts to apply established frameworks consistently. These potential biases may have influenced the extent and nature of the misconceptions identified, so the results should be interpreted with due caution.

Finally, another limitation is the geographical scope of the study, which was confined to Colleges of Education in the Eastern Region of Ghana. This limited coverage could affect the generalisability of the findings to other regions, where differences in curriculum implementation, teaching methods, or contextual factors might influence pre-service teachers' beliefs in different ways.

Conclusion

This study examined the conceptual difficulties encountered by pre-service teachers in integrated science, specifically in the areas of basic electronics, balancing chemical equations, and infectious and non-infectious diseases. It further identified and analysed the types and frequencies of alternative conceptions held by the participants. The findings revealed that pre-service teachers in Colleges of Education predominantly exhibited conceptual misunderstandings *and* factual misunderstandings, with no evidence of preconceived notions*,* nonscientific beliefs*, or* vernacular misunderstandings*,* as classified by the NRC (1997). Among the three domains investigated, balancing chemical equations proved to be the most problematic, followed by basic electronics, with infectious and non-infectious diseases presenting the fewest conceptual challenges.

The findings of this study reveal that pre-service teachers face persistent conceptual challenges not only in understanding chemical reactions and the properties of acids in chemistry but also in accurately conceptualising the processes involved in balancing chemical equations. Similarly, in physics, these difficulties extend beyond thermal contraction, the expansion properties of liquids, radiation, ozone depletion, and air pollutants, to include fundamental concepts in basic electronics. Furthermore, the results indicate that such conceptual difficulties are not confined to Ghanaian pre-service teachers; comparable patterns have been documented among their counterparts in countries such as Nigeria, Indonesia and Turkey. This convergence of evidence suggests that the challenge of mastering foundational science concepts among pre-service teachers constitutes a widespread, potentially global, phenomenon with significant implications for science education and teacher preparation.

In conclusion, the conceptual difficulties encountered by pre-service teachers in these core areas of integrated science have significant implications for the quality of science instruction at the basic school level. The findings highlight the pivotal role of teachers' content understanding in shaping student learning, as weaknesses in conceptual grasp are likely to be transmitted to learners, thereby reinforcing misconceptions and hindering the effective construction of knowledge. Addressing these gaps through targeted instructional reforms and sustained professional development is therefore imperative to strengthening science education outcomes across all levels.

Suggestions for Future Research

Based on the findings, further research is recommended in several areas. Longitudinal studies could track how pre-service teachers' misconceptions evolve, particularly under targeted instructional interventions. Designing and testing strategies such as simulations, inquiry-based learning, and diagnostic feedback would help address persistent misconceptions, especially in basic electronics and chemical equation balancing. Comparative studies across Colleges of Education may also reveal whether these misconceptions are widespread or context-specific. At the same time, investigations into language and local interpretations could clarify the role of vernacular misunderstandings. Finally, examining the influence of pedagogical content knowledge, curriculum alignment, and science anxiety would provide deeper insights into both cognitive and affective factors shaping conceptual understanding.

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Conflict of interest

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References

Adlim, M., Syahrial, S., Winarni, S., Deriyani, D., Gani, A., Rusman, R., & Salaeh, S. (2025). Understanding pre-service teachers' conceptual difficulties in learning Newman projections. *JTK (Jurnal Tadris Kimiya), 10*(1), 103–113. http://journal.uinsgd.ac.id/index.php/tadris-kimiya/index

Adu-Gyamfi, K. (2014). Challenges faced by science teachers in the teaching of integrated science in Ghanaian junior high schools. *Journal of Science and Mathematics Education, 6*(2), 59–80.

Adu-Gyamfi, K., & Ampiah, J. A. (2016). The junior high school integrated science: The actual teaching process in the perspective of an ethnographer. *European Journal of Science and Mathematics Education, 4*(2), 268–282. https://doi.org/10.30935/scimath/9469

Adu-Gyamfi, K., & Anim-Eduful, B. (2022). Interaction effect of gender, across school-type on upper-secondary students' development of experimental reasoning on organic qualitative analysis. *Journal of Baltic Science Education, 21*(3), 351–365. https://doi.org/10.33225/jbse/22.21.351

Adu-Gyamfi, K., & Asaki, I. A. (2022). Teachers' conceptual difficulties in teaching senior high school organic chemistry. *Contemporary Mathematics and Science Education, 3*(2), Article ep22019. https://doi.org/10.30935/conmaths/12382

Adu-Gyamfi, K., & Asaki, I. A. (2023). Factors contributing to teachers' conceptual difficulties in teaching high school organic chemistry. *European Journal of Science and Mathematics Education, 11*(1), 49–67. https://doi.org/10.30935/scimath/12433

Adu-Gyamfi, K., Ampiah, J. G., & Appiah, J. Y. (2013). Senior high school chemistry students' performance in IUPAC nomenclature of organic compounds. *Cypriot Journal of Educational Sciences, 8*(4), 472–483.

Adu-Gyamfi, K., Ampiah, J. G., & Appiah, J. Y. (2017). Students' difficulties in IUPAC naming of organic compounds. *Journal of Science and Mathematics Education, 6*(2), 77–101.

Adu-Gyamfi, K., Arthur, N., & Anim-Eduful, B. (2024). Teacher general pedagogy and subject matter knowledge for teaching qualitative analysis concepts to chemistry students. *International Education and Culture Studies, 4*(1), 24–45. https://doi.org/10.71002/iecs.v4n1p24

Akram, M., Aziz, S., Zafar, J. M., & Asghar, M. (2022). Conceptual difficulties of elementary school students in the subject of general science. *Pakistan Journal of Humanities and Social Sciences, 10*(1), 43–49. https://journals.internationalrasd.org/index.php/pjhss

Anim-Eduful, B., & Adu-Gyamfi, K. (2021). Functional groups detection: Do chemistry teachers demonstrate conceptual difficulties in teaching? *Global Journal of Human-Social Science G: Linguistics & Education, 21*(7), 47–60. https://doi.org/10.34257/GJHSSGVOL21IS7PG47

Anim-Eduful, B., & Adu-Gyamfi, K. (2022a). Chemistry students' conceptual understanding of organic qualitative analysis. *Pedagogical Research, 7*(4), Article em0132. https://doi.org/10.29333/pr/12307

Anim-Eduful, B., & Adu-Gyamfi, K. (2022b). Factors influencing high school chemistry teachers' and students' teaching and learning of organic qualitative analysis: A qualitative study. *European Journal of Education Studies, 9*(7), 194–219. https://doi.org/10.46827/ejes.v9i7.4378

Anim-Eduful, B., & Adu-Gyamfi, K. (2023). Nature of senior high school chemistry students' alternative conceptions in organic qualitative analysis. *Aquademia, 7*(2), Article ep23007. https://doi.org/10.29333/aquademia/13711

Ansah, F. O., Amoah, C. A., & Baah, K. A. (2018). Assessing pre-service teachers' conceptual understanding on "amount of substance and the mole" in Ghana. *International Journal of Science and Research, 7*(4), 2319–2364.

Arokoyu, A. A. (2012). Elements of contemporary integrated science curriculum: Impacts on science education. *Global Journal of Educational Research, 11*(1), 49–55.

Azure, J. A. (2015). Senior high school students' views on the teaching of integrated science in Ghana. *Journal of Science Education and Research, 1*(2), 49–61.

Baah, R., & Ampiah, J. G. (2012). Senior high school students' understanding and difficulties in writing chemical equations. *International Journal of Scientific Research in Education, 5*(3), 162–170.

Carrier, S. J., Sachs, L. H., McGowan, J. M., Hayes, M., Smith, P. S., Goforth, C. L., & Safley, S. E. (2025). Elementary teachers as collaborators: Developing educative support materials for citizen science projects. *International Journal of Science Education, 47*(1), 107–127. https://doi.org/10.1080/09500693.2024.2373319

Cohen, L., Manion, L., & Morrison, K. (2010). *Research methods in education* (6th ed.). Routledge-Falmer.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th ed.). Sage Publications.

Dewhirst, C. B. (2023). Exploring the cognitive apprenticeship approach in teacher education: A case study of an early childhood practicum experience. *Early Child Development and Care, 193*(8), 965–978. https://doi.org/10.1080/03004430.2023.2187326

Dula, D. E. (2018). Improving the problems of writing chemical symbols, formulae and chemical equations: An action research. *Annals of Reviews and Research, 4*(3), 51–59.

Halim, L., Yong, T., & Meeran, S. (2014). Overcoming students' misconceptions on forces in equilibrium: An action research study. *Creative Education, 5*(10), 1032–1042. https://doi.org/10.4236/ce.2014.511117

Hanson, R. (2017). Enhancing students' performance in organic chemistry through context-based learning and micro activities: A case study. *European Journal of Research and Reflection in Educational Sciences, 5*(6), 7–20.

Kabapınar, F., Tekin, D., & Tetik, S. (2025). Exploring pre-service chemistry teachers' understanding of scientific inquiry skills through the chemistry laboratory course. *Science Insights Education Frontiers, 28*(2), 4637–4656. https://doi.org/10.15354/sief.25.or781

Kariper, I. A. (2011). An investigation into the misconceptions, erroneous ideas and limited conception of the pH concept in pre-service science teacher education. *The Chemical Education Journal, 14*(1), 105–122.

Khmel, N., & Shpyrka, Z. (2025). Studying chemistry at school: Overcoming challenges together. *Journal of Vasyl Stefanyk Precarpathian National University, 12*(1), 151–160. https://doi.org/10.15330/jpnu.12.1.151-160

Kooiker-den Boer, H. S., Sanders, T. J., & Evers-Vermeul, J. (2025). Integrating text structure instruction in science education: A design-based study. *Journal of Science Teacher Education, 36*(1), 48–71. https://doi.org/10.1080/1046560X.2024.2373548

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement, 30*(3), 607–610. https://doi.org/10.1177/001316447003000308

Kuczmann, I., & Budapest, N. F. G. (2017). The structure of knowledge and students' misconceptions in physics. *AIP Conference Proceedings, 1916,* Article 050001. https://doi.org/10.1063/1.5017455

Lee, S. J., & Kriewaldt, J. (2025). Where powerful knowledge and pedagogical content knowledge intersect: The case of knowledge and beliefs for teaching school geography through inquiry. *International Research in Geographical and Environmental Education, 34*(1), 79–94. https://doi.org/10.1080/10382046.2024.2348274

Li, J., & Singh, C. (2017). Investigating and improving introductory physics students' understanding of the electric field and the superposition principle. *European Journal of Physics, 38*(5), Article 055702. https://doi.org/10.1088/1361-6404/aa7c51

McColgan, M. W., Finn, R. A., Broder, D. L., & Hassel, G. E. (2017). Assessing students' conceptual knowledge of electricity and magnetism. *Physical Review Physics Education Research, 13*(2), Article 020121. https://doi.org/10.1103/PhysRevPhysEducRes.13.020121

Mensah, F., & Somuah, A. B. (2013). The teaching of science: Challenges and prescription. *Journal of Education and Practice, 4*(22), 24–35.

Ministry of Education. (2010). *Teaching syllabus for chemistry: Senior high school.* http://bit.ly/4nqYQg7

National Research Council. (1997). *Science teaching reconsidered: A handbook.* National Academy Press.

Ofori-Appiah, C., Safo-Adu, G., Quansah, R. E., & Ngman-Wara, E. (2018). Competency level of senior high school biology teachers and their attitudes toward organising practical work in Eastern Region of Ghana. *International Research Journal of Curriculum and Pedagogy, 6*(1), 112–124.

Ogundiji, O. (2024). Diagnosis of students' difficulties in balancing chemical equations in some selected senior secondary schools in Ibadan, Nigeria. *Journal of General Education and Humanities, 3*(4), 359–368. https://orcid.org/0009-0007-1158-5349

Onder-Celikkanli, N., & Tan, M. (2022). Determining Turkish high school students' misconceptions about electric charge imbalance by using a four-tier misconception test. *Physics Education, 57*(5), Article 055010. https://doi.org/10.1088/1361-6552/ac68c1

Otarigho, M. D., & Djabo, D. D. (2013). Problems and prospects of teaching integrated science in secondary schools in Warri, Delta State, Nigeria. *TechnoLearn: An International Journal of Educational Technology, 3*(1), 19–26.

Pascual, J. M., & Noble, D. (2025). What genes can and cannot do. In R. Rosenberg (Ed.), *Molecular and genetic basis of neurological and psychiatric disease* (pp. 63–74). Academic Press. https://doi.org/10.1016/B978-0-323-85780-2.00005-2

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227. https://doi.org/10.1002/sce.3730660207

Quansah, R. E., Sakyi-Hagan, N. A., & Essiam, C. (2019). Challenges affecting the teaching and learning of integrated science in rural junior high schools in Ghana. *Science Education International, 30*(4), 329–333.

Sakpaku, D. (2016). Exploring the perception of junior high school teachers and students on topics in the integrated science syllabus (Unpublished doctoral dissertation). University of Cape Coast.

Somuah, B. A., & Agyenim-Boateng, E. O. (2014). The teaching of integrated science and teacher support services. *Journal of Educational and Social Research, 4*(3), 11–20.

Taber, K. S. (2011). Models, molecules and misconceptions: A commentary on "Secondary school students' misconceptions of covalent bonding." *Journal of Turkish Science Education, 8*(1), 3–18.

Twissell, A. (2018). Modelling and simulating electronics knowledge: Conceptual understanding and learning through active agency. *Educational Technology & Society, 21*(2), 111–123.

WAEC. (2013). *West Africa senior secondary certificate examination (school candidates): Chief examiners' report science, May/June.*

WAEC. (2015). *West Africa senior secondary certificate examination (school candidates): Chief examiners' report science, May/June.*

WAEC. (2016). *West Africa senior secondary certificate examination (school candidates): Chief examiners' report science, May/June.*

WAEC. (2018). *West Africa senior secondary certificate examination (school candidates): Chief examiners' report science, May/June.*

WAEC. (2021). *West Africa senior secondary certificate examination (school candidates): Chief examiners' report science, May/June.*

Wang, T. L., & Berlin, D. (2010). Construction and validation of an instrument to measure Taiwanese elementary students' attitudes toward their science class. *International Journal of Science Education, 32*(18), 2413–2428. https://doi.org/10.1080/09500690903431561

Winarno, N., Rusdiana, D., Riandi, R., Susilowati, E., & Afifah, R. M. A. (2020). Implementation of integrated science curriculum: A critical review of the literature. *Journal for the Education of Gifted Young Scientists, 8*(2), 795–817. https://doi.org/10.17478/jegys.675722

Wolff, M., Hammoud, M., & Carney, M. (2023). Developing master adaptive learners: Implementation of a coaching program in graduate medical education. *Western Journal of Emergency Medicine, 24*(1), 71–75. https://doi.org/10.5811/westjem.2022.12.57636

Yadav, A., Lachney, M., Hill, R., Lapetina, A., Hu, A. D., Jee, H., & Allen Kuyenga, M. C. (2025). Diving into the role: A multi-case study on supporting novice CS teachers' knowledge through co-teaching. *Journal of Research on Technology in Education, 57*(1), 125–144. https://doi.org/10.1080/15391523.2023.2217854

Yin, F., & Goller, T. (2024). Embodied schema information processing theory: An underlying mechanism of embodied cognition in communication. *Communication Theory, 34*(3), 154–165. https://doi.org/10.1093/ct/qtae010